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The status, predicament and countermeasures of biomass secondary energy production in China

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A B S T R A C T

China is rich in biomass resources, with favorable conditions for the development and utilization of biomass energy. Currently, the main secondary forms of biomass energy utilized in China include biogas, biomass power, bioethanol, biodiesel. By the end of 2010, the annual output of biogas in China had reached 14.3×10^9 m^3; the installed capacity of biomass power had reached 5.5×10^6 kw; the annual output of bioethanol had reached 1.84×10^6 t; the annual output of biodiesel was 400×10^3 t. Although China is very rich in biomass resources, the percentage of biomass energy in the total energy utilized in China is very low. In 2010, the biomass secondary energy accounted for 7.28% of the total renewable energy consumption; and only 0.66% of the primary energy consumption in China. Compared with other types of renewable energy, the biomass energy development remains very slow and even marginalized. The development of secondary sources of energy in China is relatively slow, the reasons for which are many, such as food security, high production costs, obsolete equipment, technological immaturity, insufficient raw materials, and a serious shortage of investments. In fact, the root causes for the slow development of the biomass secondary energy industry are the government's focus on economic development and the private enterprises focus on economic benefits. The lower economic benefits of the biomass secondary energy industry do not intrinsically motivate them to promote its development. Entering the market is crucial to the development of the biomass secondary energy and requires strong implementation and policy guarantees by the government. Biomass secondary energy has a positive role in reducing greenhouse gas emission, reducing waste pollution, and increasing employment opportunities. It is recommended that the government and enterprises should actively promote the development of the biomass secondary energy.

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1. Introduction

Energy plays a vital role in the socio-economic development and the rising standards of living of human beings [1]. The energy security problem has existed since the industrial revolution. Along with enjoying the benefits brought forth by energy, such as economic development, technological progress and other interests, human beings have also encountered a series of unavoidable energy security challenges. The extensive use of fossil fuels generates considerable amounts of greenhouse gases and other harmful gases. It has been accepted worldwide that the global warming is by far the greatest threat and challenge to human being [2]. Due to the warming effect caused by CO_2, CH_4, N_2O and other greenhouse gases, global warming has not been in doubt. In the last 100 years (1906–2005), the global temperature has increased by 0.74 °C [3]. Extensive use of fossil energy is the key reason for the increase in greenhouse gas emission. Energy sources have become a focus of legal, ethical, social and economic pressures due to increasing environmental problems [4].

Biomass energy is one of humanity's earliest sources of energy, particularly in rural areas where it is often the only accessible and affordable source of energy [5]. The associated harmful environmental, health and social effects with the use of traditional biomass and fossil fuel have enhanced the growing interest in the search for alternate cleaner source of energy globally [6]. Renewable energy is one of the most efficient ways to achieve sustainable development. The future of sustainable energy depends on increased sharing of renewable energy, especially in developing countries [7]. Secondary energy based on biomass is a very good form of renewable energy. The so-called biomass secondary energy refers to the energy obtained from biomass processing and transition, generally including bioethanol, biodiesel, biogas, biomass power, bio-methanol. Compared with biomass primary energy, biomass secondary energy is relatively clean, highly efficient, easy to store and easy to transport. Many countries in the world use biomass to make biofuels. During the last decade, countries around the world especially the US, Brazil, and many countries in Europe have worked to accelerate the commercialization of the biofuel industry [8]. Renewable energy sources supply 14% of the total energy demand of the world [9]. The next few decades will require a massive growth of the bioenergy industry to address the societal demands to reduce the net carbon emission [10].

Biomass energy is the main energy source in rural China [11]. The earliest widely used biomass secondary energy in China was biogas. In the beginning of the 21st century, the Chinese government realized that the development of the renewable energy industry plays a major role in responding to the energy crisis. In 2006, China developed the *Mid-Long Term Development Plan for Renewable Energy* [12]. Biomass secondary energy is an important part of the *Mid-Long term Development Plan for Renewable Energy*. Development of the biofuel industry can solve the unemployment problem, and can stimulate the development of a variety of industries, including the agricultural industry, the chemical industry, the plastics industry, the automotive industry, the lighting industry, the electrical industry, the transportation industry, the service industry, and so on. The development of the biofuel industry is the most realistic measure towards emission reduction, which will help China realize its commitment to reduce its emissions of CO_2 by 40–45% by 2020 [13]. Because the energy demand has grown faster in the developing countries than in the developed countries, the energy crisis has become a serious threat to sustainable development in the developing countries. China's dependence on foreign energy is high. Despite the abundant biomass resources, the development of the biomass industry in China is slow and almost in a predicament. Compared to other new energy industries such as the wind energy industry and the electrical energy industry, the biomass energy industry has suffered an embarrassing situation of 'critical success without commercial popularity' [14]. In studying China's biomass energy industry, most scholars have based their analysis on technology, raw materials, markets, funds, and so on [15,16]. However, Shi [17] reveals that the reason why China does not attach importance to the development of biomass energy is rooted in its economic interests. The development of the biomass energy industry has a great potential for improving China's energy structure and reducing greenhouse gas emissions. This paper will explore the cause of the predicament of the Chinese biomass secondary energy industry and explore possible solutions for it by analyzing biomass secondary energy development in recent years.

2. Biomass secondary energy in China

2.1. Framework of biomass secondary energy production in China

Biomass generally includes agricultural and forest biomass, livestock manure, industrial organic waste, organic domestic garbage. China is a large agricultural country and its biomass resources are very rich, with good conditions for biomass development and utilization [18]. The biomass secondary energy is the energy comes from biomass conversion or upgrade. The biomass conversion refers to direct biomass burning and biomass upgrade process includes separation, liquefaction, pyrolysis, hydrolysis, fermentation, and gasification of biomass. The framework of biomass secondary energy in China is shown in Fig. 1.

From Fig. 1, it can be observed that there are various types of biomass secondary energy. The important types of biomass secondary energy include biomass power, bioethanol, biodiesel and biogas. Biogas is considered as an intermediate product obtained before pure bioethanol. Elsewhere, biogas after purification is generally used as biomass secondary energy. The unpurified biogas is widely used as a primary energy in rural areas in China, benefiting over 150 million people. Therefore, biogas is treated as a secondary energy in this figure and in the following paragraphs for discussion.

2.2. Development status of the biomass secondary energy in China

The biomass secondary energy in China first began with the biogas project. Large amounts of small-scale bioenergy projects were carried out in China's rural areas as part of its national renewable energy policies [20]. Other types of biomass secondary energy such as biomass power, bioethanol, and biodiesel are being gradually developed in China. In 2010, the renewable energy

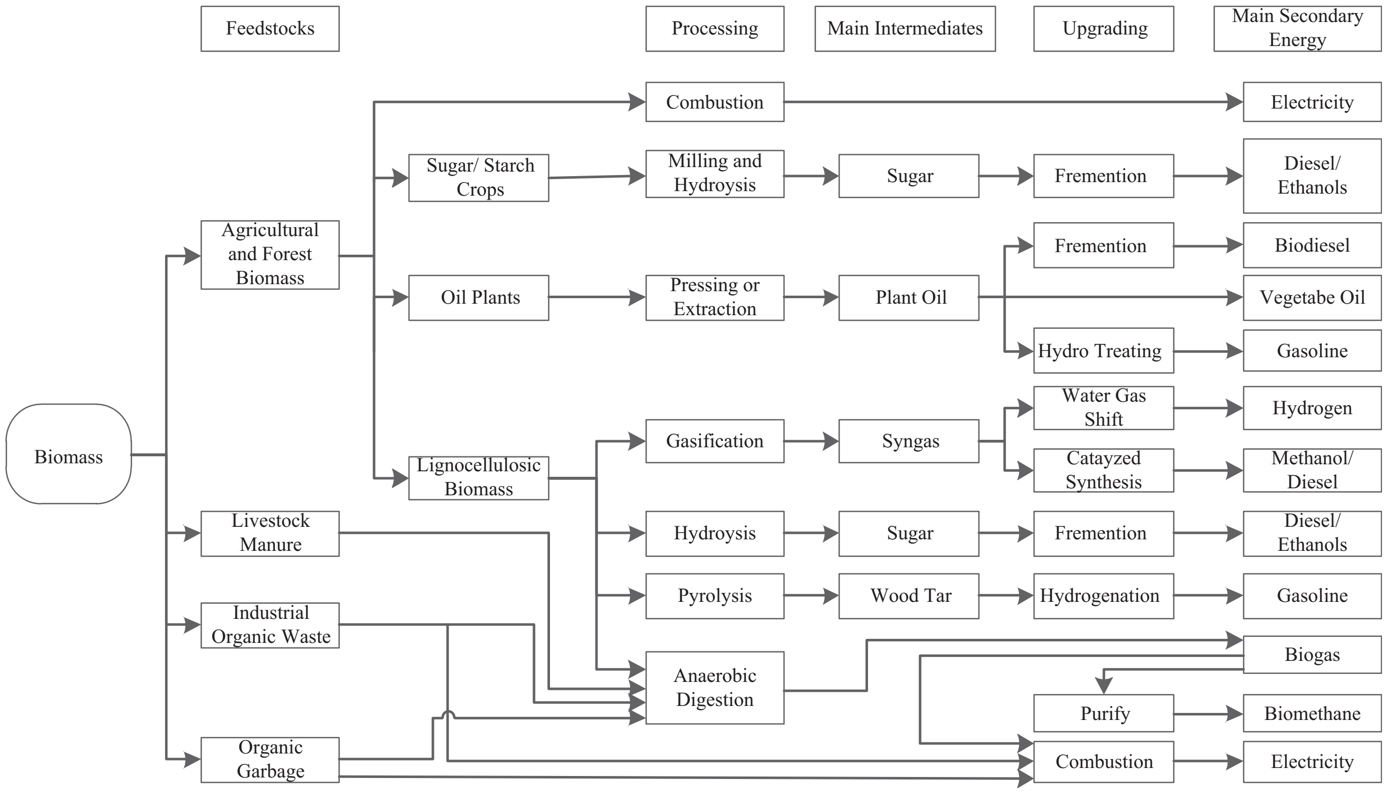


Fig. 1. Framework of biomass secondary energy in China. Note: agricultural and forest biomass are based on the IPCC special report [19] and partially modified.

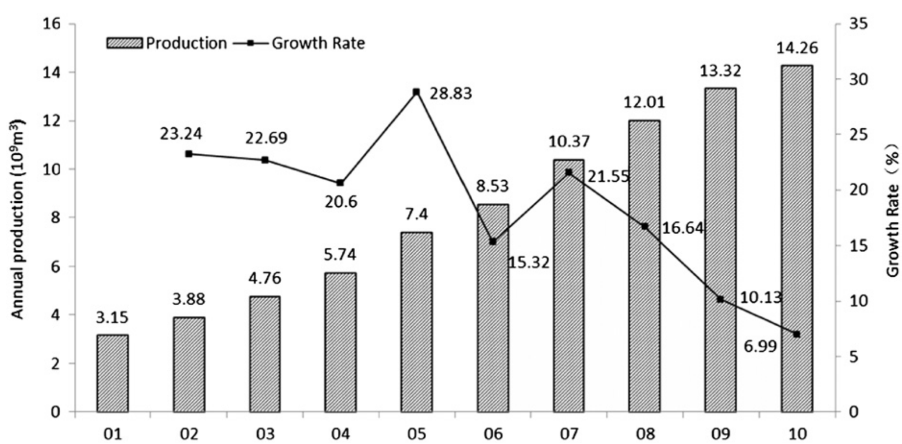


Fig. 2. Biogas production and growth rate in 2001–2010 [24].

accounted for 9.09% of China's primary energy consumption; the biomass secondary energy accounted for 7.28% of the renewable energy consumption and only 0.66% of the primary energy consumption [21].

2.2.1. Development status of biogas in China

Biogas is a promising renewable fuel [22]. The production of biogas as a renewable resource has emerged rapidly in many countries, with the expectation to substantially mitigate anthropogenic greenhouse gases [23]. Since the early 1970s, the Chinese government has been extending the biogas industry into rural areas. The biogas generated from the biogas digesters was first used for cooking and was later used for lighting and heating. By the end of 2010, the number of rural households in China using biogas had reached 38.508 million, which is approximately 30% of the suitable households. By the end of 2010, the total biogas production in China had reached $14.3 \times 10^9\ m^3$ (Fig. 2), of which the total biogas used for rural households was $1.3 \times 10^{10}\ m^3$, and the biogas usage per rural household was 384 m^3; 72,695 agricultural waste processing projects (including small, medium and large biogas projects)yielded an annual total biogas production of $1.05 \times 10^9\ m^3$; 322 industrial waste processing projects yielded an annual total biogas production of $0.13 \times 10^9\ m^3$ [21]

The biogas technology, besides supplying energy and manure, provides an excellent opportunity for mitigating greenhouse gas emissions and reducing global warming by measures such as substituting firewood for cooking, kerosene for lighting and cooking and avoiding chemical fertilizers [25]. Environmental analysis shows that the use of biogas makes a substantial contribution towards optimizing the energy consumption structure, reducing

energy consumption, discharging less harmful gases and maintaining the balance of the ecosystem [26]. The development of biogas projects in China is relatively smooth. Although the total production of biogas in China has been growing, the growth rate clearly shows a downward trend. The increase in the biogas production is mainly due to the promotion of the use of biogas in rural household biogas. The industrialization of biogas is not smooth.

From the proportions of the biogas components in China in 2001 and 2010 (Fig. 3), we can see that the proportion of household biogas has declined but is still above 90%; the proportion of agricultural biogas project increased a great deal, from 1.11% in 2001 to 7.39% in 2010, while the industrial waste biogas project remained relatively stable in its total amount, but its proportion fell from 4.22% in 2001 to 0.88% in 2010 and its decline is very obvious.

2.2.2. Development status of biomass power generation in China

Biomass power generation mainly uses the biomass from agriculture, forestry, industrial waste, municipal refuse, as raw materials, using direct burning or gasification as the means to generate power. Global biomass power generation originated in the 1970s. The outbreak of a global oil crisis caused Denmark and Sweden and other countries to use renewable energy and adjust their energy structure. They vigorously promoted straw biomass power and soon gained the attention of the major developed countries. Thereafter, biomass power generation developed rapidly. China's biomass power generation began in 2004; the National Development and Reform Commission ratified the first three biomass power generation projects, which were established in the provinces of Shandong, Hebei, and Jiangsu. At the end of 2006, the biomass power generation project (with a 1×2.5 kw generating unit) in Dan County, Shandong Province, was put into operation, taking the lead in biomass power generation by direct combustion.

From 2006 to 2010, China's biomass power generation made great progress (Fig. 4). From the data on the biomass power generation installed capacity and the growth rate in 2006–2010, we observe that during 2006–2010, the total installed capacity of biomass power generation in China increased every year, increasing from 140 million kw in 2006 to 550 million kw in 2010, but the growth rate showed a declining trend, dropping from 57.14% in 2004 to 27.91% in 2010.

2.2.3. Development status of bioethanol in China

Fuel ethanol is considered one of the most important renewable fuels due to the economic and environmental benefits of its use [28]. The bioethanol project in China began in 2004. At that time four pilot ethanol projects were established in the provinces of Heilongjiang, Jilin, Henan and Anhui. In 2006, China ceased starting new bioethanol projects that use aged grain as raw materials and encouraged the development of bioethanol projects that use non-food crops as raw materials. The annual production of bioethanol and its growth rate in 2005–2010 (Fig. 5) shows that China's bioethanol production grew at a steady rate when compared to the other types of biomass secondary energy, but its annual increment was not sufficiently large (Fig. 5).

2.2.4. Development status of biodiesel in China

The research of biodiesel in China began in the eighth five-year period. The most important factor in the biodiesel industry is the raw materials because the cost of the raw materials accounted for 75% of the total cost, playing a decisive role in the price of biodiesel. Currently, the main raw materials used in the world for biodiesel production are rapeseed oil (which comprises approximately 50% of the total raw materials), soybean oil, palm oil and sunflower seed oil; the proportions of other raw materials are smaller. In China, due to its special national conditions, the main raw materials for biodiesel production are waste oil (including drainage oil), acidic oil, residual vegetable oil. Large application of plant sources from forest energy needs further development. China's 11th five-year plan proposed to utilize 2 million tons of biodiesel in 2010. Currently, there are 74 biodiesel plants in China, with a total production of 2 million tons/year; in 2010, the actual production of biodiesel in China was 400,000 t [20]. In the future, the production of biodiesel may be dominated by new types of biodiesel production technology. Microalgae have been

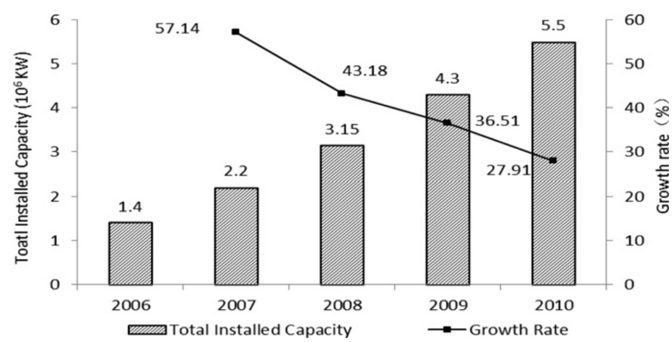


Fig. 4. Biomass power generation installed capacity and growth rate in2006–2010 [27].

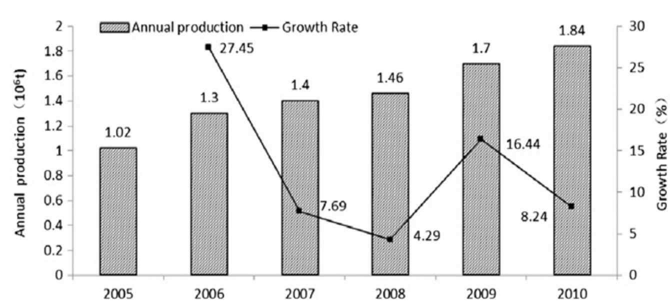


Fig. 5. Annual production of bioethanol and the growth rate in 2005–2010 [21].

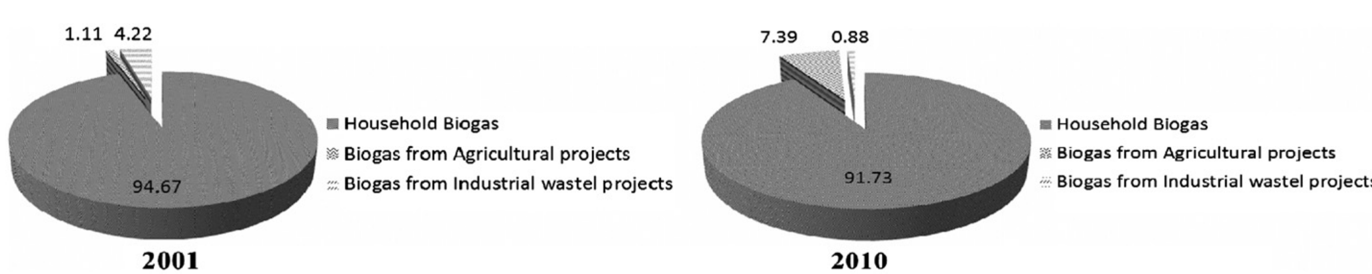


Fig. 3. Proportion of the biogas components in China in 2001 and 2010 (%) [21].

proposed as possible alternate feedstock for the production of biodiesel because of their high photosynthetic efficiency [29].

3. Predicament of the development of the biomass secondary energy

3.1. Slow rate of the development of bioenergy

According to China's *Mid-Long term Development Plan for Renewable Energy* [12], the actual production of renewable energy in 2005, the objective and actual production of 2010, and the objective for 2020 are shown in Table 1.

In recent years, the biomass secondary energy has grown to a certain extent in China. However, this growth has masked the fact that: the development of the biomass secondary energy is much lower than that of other types of renewable energy in China. Although the growth of China's biomass secondary energy in recent years has maintained a steady, albeit slow rate and has essentially reached its proposed objective in 2010, renewable energy from non-biomass sources, especially wind and solar energy, have shown tremendous growth in recent years; China's wind power generation capacity in 2010 reached 31×10^6 kw, meeting 620% of the objective; the solar power generation capacity reached 1×10^6 kw, meeting 330% of the objective. For some types of biomass secondary energy, the generation capacity exceeded the objective for 2010, while for the other types, the generation capacity was below the objective for 2010. For example, biogas production met only 75% of the objective. According to the 2012 China Energy Work Conference [30] report, in 2011, China's wind power generation capacity increased by 16×10^6 kw, resulting in a total capacity of 47×10^6 kw; the photovoltaic power generation had a strong growth, with a capacity of 3×10^6 kw, which is 300% of the objective for 2010; however, for biomass secondary energy, the production was ignored and even the relevant information could not be found. Evidently, compared to other types of renewable energy, biomass secondary energy has been seriously neglected in China. Against the background of increasing demands for energy in China, the development of the biomass secondary energy is passive. Even though bioenergy provides a significantly greater contribution towards the global primary energy supply than do all the existing and planned wind and solar projects together [31], the development of biomass secondary energy remains in a predicament in China.

3.2. Development of bioenergy is gradually marginalized

China's *Mid-Long term Development Plan for Renewable Energy* [12] recommended to 'make full use of renewable energy with mature technology and economic benefits including hydropower, biogas, solar thermal and geothermal energy, etc, accelerating the development of wind power, biomass power generation, and solar power, and gradually improve the quality proportion of clean and renewable energy in the energy structure, and strive to make renewable energy consumption account for 10% of the total energy consumption in 2010, and reach 15% in 2020'. In the national energy conferences in recent years, the objective for nuclear energy generation has been increased by 15%, while bioenergy has been listed among other types of renewable energy. The United Nations normally considers large hydropower as traditional energy, and according to this convention, the actual consumption proportion of renewable energy is only 7.5% of renewable energy [32]. As the Chinese government dominates the development of renewable energy, the development of bioenergy has been slow and has even begun to disappear from the development objectives, which shows that the development of the bioenergy industry in China has begun to be marginalized.

4. Countermeasures

4.1. Analyses of key reasons

The biomass resources in China are rich, but the development of biomass secondary energy is relatively slow. There are many reasons for this, but generally, the key reasons restricting the development of biomass secondary energy in China are

(1) Impact to food security: a strategic shift from food-based biofuel to non-food-based biofuel is a general trend; because China has halted bioethanol projects that used grain as a raw material, food security concerns can be relieved [16]. Food cannot be the reason to deny the development of bioenergy [15].
(2) High production cost: for example: the cost of corn-based fuel ethanol is 8000–9000 Yuan per ton; two tons of refined oil can be bought at this price; the cost of straw power generation for the grid is 0.834Yuan/kw h; in fact, including the subsidy, the cost of straw power generation for the grid is 0.746 Yuan/kw h [20].
(3) Obsolete equipment and immature technology: China's innovative strength in bioenergy technology is weak; advanced technical equipment and high-tech materials are mostly from foreign countries; and China's research on system integration is far behind that of other developed countries, which has seriously hampered the development of the bioenergy industry [15].
(4) Insufficient production of raw materials: China has huge amount of biomass, with scattered distribution and strong seasonal trends [15,33]. This situation requires the government's macro-control to optimize the allocation of sites for bioenergy plants [34] to avoid the waste of biomass in some

Table 1
Developments of China's major renewable energy.

	2005	2010[a]	2010[b]	2020
Installed capacity of hydropower (GW)	0.12	0.19	0.21	0.3
Biomass power generation (kw)	2×10^6	5.5×10^6	5.5×10^6	30×10^6
Biogas (m^3)	8×10^9	19×10^9	14.3×10^9	40×10^9
Bioethanol (t)	1.02×10^6	2×10^6	2×10^6	10×10^6
Biodiesel (t)	50×10^3	200×10^3	360×10^3	2000×10^3
Installed capacity of wind power (kw)	1.26×10^6	5×10^6	31×10^6	30×10^6
Installed capacity of solar power (kw)	0.07×10^6	0.3×10^6	1×10^6	1.80×10^6

[a] Means objective production.
[b] Means actual production.

places and prevent similar enterprises from appearing in the same place.

(5) Incomplete support polices: although the *Renewable Energy Law of the People's Republic of China* [35] has been issued, the legal system remains incomplete, lacking reasonable and effective incentive polices in the fiscal, financial and market sectors. For example, non-food based liquid biofuel cannot enter the market and enjoy government subsidies; the pricing mechanism of bioenergy has not reflected the associated environmental benefits [36].

(6) Serious shortage of investments: bioenergy belongs to a high-tech industry that is new and needs huge investments in its technology development and market cultivation. However, its financing sources are relatively homogeneous. A serious shortage of governmental investment results in a weak capacity for research and development in some fields and a low technological level, both of which hamper technical innovation and industry development [36].

We suggest a number of methods to solve the problems. For example, prohibit the production of bioethanol with grain; improve subsidies for biomass power generation for grids; actively promote financing for bioenergy enterprises. In August of 2008, the Chinese National Development and Reform Commission issued the *Notice on the Management of Biomass Power Generation Project Construction* [37], which provided guidance regarding the policy to solve problems in duplicate construction and competition for fuel at the same place, which impact the industrial development of biomass power generation plants. Most of obstacles to the development of the biomass industry in China had been solved [16]. However, eventually, the trend of growth rate of biomass secondary energy in China is decreasing. It seems that we have not found the vital factors restricting the development of the biomass industry. The key reason for the slow development of biomass secondary energy in China is that the government and private enterprises lack the motivation to promote the development of the bioenergy industry. Shi [17] pointed out that 'today in the process of promoting industrialization and market economy in China, two types of people have a vital role in policy formulation, one is senior officials of the government who are in charge of business, the other is senior management staff of large central enterprises, there are inextricable links with right and interests between these two types of people'. Evidently, compared to industries such as the coal industry, the gasoline industry and the natural gas industry, which dominate the energy market and can quickly obtain substantial interests, the biomass secondary energy industry currently needs subsidies for operation, which certainly does not appeal to the interest of the governmental officials and the senior management staff of central enterprises. The government officials and the executives of enterprises have no intrinsic motivation to promote the development of biomass secondary energy in China because of low economic benefits. So, they have no motivation to strengthen legalization and related safeguards. Because of incomplete support policies, the investment in this field has been insufficient, which resulted in obsolete equipment, immature technology and high production cost. So we need to make more complete policies to ensure a sufficient investigation to be made before a new biomass secondary energy investment plan, which can avoid that investments will not be placed on technology that may soon become obsolete and encourage enterprises to invest the biomass secondary energy by increasing the degree of subsidies.

4.2. Key to solving the problems

In China, petrochemical resources are scarce, and bioenergy has not yet been put to good use. To really promote the development of the biomass secondary energy in China, it is required to not only clearly know that the lack of an intrinsic motivation on the part of the government officials and the executives of enterprises is the root cause for the slow development of the biomass secondary energy, but it is also required to find out the key to solving the problems from the supply chain. Bioenergy is increasingly becoming a globally traded energy commodity [38]. There are currently strong incentives for the increased use of renewable fuels in the transportation sector worldwide [39]. Evidently, making biomass secondary energy easily accessible in the commodity market is a very important part of the solution. Emerging renewable energy technologies cannot break through without the involvement of entrepreneurs [40].

We take the supply chain of bioethanol as an example to explore how to promote the development of the biomass secondary energy in China, as shown in Fig. 6. In the supply chain, the most critical sector involves the ethanol hybrid and its distributors who make bioethanol enter into gas stations and finally reach the user. Effective distribution requires active cooperation from large-scale petrochemical enterprises, which have a monopoly in China. Without their cooperation, the marketing of the hybrid bioethanol cannot be truly extended. However, these enterprises are also the vested interests of the dominant conventional resources such as coal, gasoline and natural gas. In order for

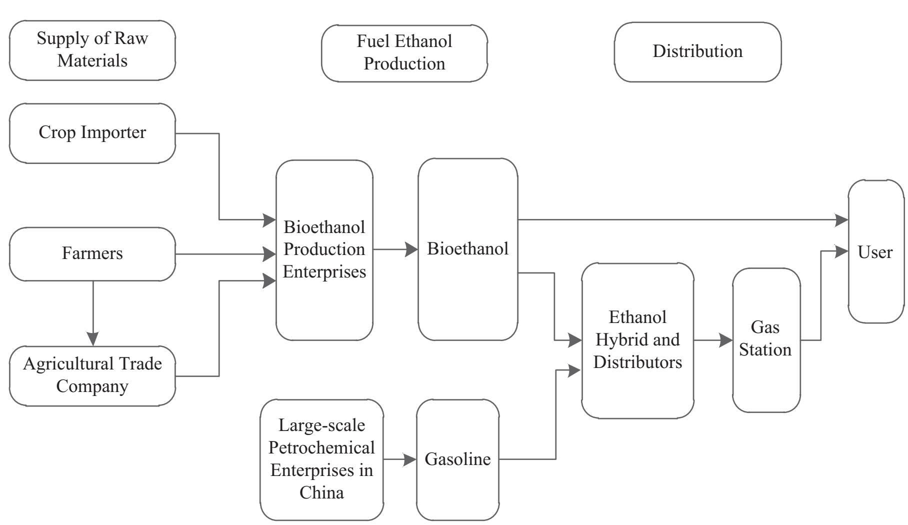


Fig. 6. Supply chains of the Chinese bioethanol project.

these enterprises to lay down a part of their interests and promote the hybrid ethanol with higher costs, two factors are required: one is that the government and enterprises must change their thinking and understand that developing biomass secondary energy is an important safeguard for future energy security, and the other is that the government must make strong policies to implement.

The impetus behind the increase in ethanol production is the US policy to increase the production and use of renewable fuels [41]. The biomass producer needs 'stronger market intervention' [42]. Apparently, to promote the development of biomass secondary energy, the government must dare to give up a part of its economic interests and strengthen policy promotion to truly promote the development of biomass secondary energy and reduce greenhouse gas emissions.

5. Conclusions

Biomass resources in China are abundant but have not been used comprehensively. The proportion of the biomass secondary energy used in China in 2010 was 7.28% of the total renewable energy used and only 0.66% of the total consumption of primary energy. The development of biomass secondary energy is far behind other types of renewable energy in China and is even in a trend of marginalization.

The root cause for the slow development of biomass secondary energy in China is its low economic benefits, which does not intrinsically motivate the government officials and the executive of enterprise to promote the development of biomass secondary energys. However, the development of biomass secondary energy can not only reduce greenhouse gas emissions and mitigate pollution but can also can provide many employment opportunities and improve people's standard of living. To promote the development of biomass secondary energy in China and escape the current predicament, the following are recommended: firstly, the government should enforce the entrance of biomass secondary energy into power grid and gas stations by means of industrial biogas entering into the natural gas pipeline network, biomass power generation entering into the power grid, ethanol fuel entering into gas stations, and easy access to products in the market; secondly, the government must consider the social benefits of biomass secondary energy and increase the subsidies of biomass secondary energy by drawing out a considerable portion of funds from the profits and taxes of dominant energy industries such as the gasoline and coal industries, which can not only promote the development of the biomass secondary energy but can also effectively restrict the overdevelopment and overuse of oil and coal. Finally, to solve other problems associated with the development of the biomass secondary energy industry in China, the following measures should be taken: strengthening the optimal allocation of resources; avoiding waste and competition for biomass resources; improving legislation and strengthening legal safeguards; and multiplying the sources of financing to strengthen research and production for biomass secondary energy.

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